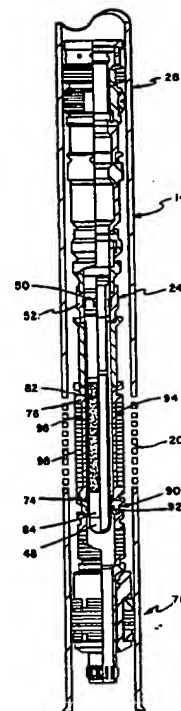




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁵ : E21B 43/08, 43/12, 23/02 E21B 33/12	A1	(11) International Publication Number: WO 94/03705 (43) International Publication Date: 17 February 1994 (17.02.94)
(21) International Application Number: PCT/US93/07146 (22) International Filing Date: 29 July 1993 (29.07.93) (30) Priority data: 07/921,922 29 July 1992 (29.07.92) US (71) Applicant: HALLIBURTON COMPANY [US/US]; 2601 Beltline Road, Carrollton, TX 75006 (US). (72) Inventor: RESTARICK, Henry, Louis ; 1908 Templehill Drive, Plano, TX 75075 (US). (74) Agent: GRIGGS, Dennis, T.; Glaser, Griggs & Schwartz, 5430 LBJ Freeway, Suite 1540, Dallas, TX 75240 (US).		(81) Designated States: NO, RU, European patent (DE, DK, GB, IT, NL). Published <i>With international search report.</i>
(54) Title: SINTERED SCREEN COMPLETION (57) Abstract <p>A sintered metal screen (S1) is releasably suspended from a packer mandrel (26) by a locking mandrel (50) and a landing nipple (24). The sintered metal screen (S1) and locking mandrel (50) are retrievable with the assistance of a running tool which is insertable into the bore of the locking mandrel. According to this arrangement, the sintered metal sand screen may be removed and replaced without retrieving the packer (28) or the production tubing (34). In one embodiment, the sintered metal screen is enclosed within the bore of a sliding side valve (62). The sliding side valve (62) may be opened and closed as desired for selectively admitting production from various producing zones, or for isolation of a damaged screen. In another embodiment, an auxiliary sintered metal screen (82) is inserted into the bore of a primary screen, for example, a conventional wire-wrap sand screen (94).</p>		



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FR	France	MR	Mauritania
AU	Australia	GA	Gabon	MW	Malawi
BB	Barbados	GB	United Kingdom	NE	Niger
BE	Belgium	GN	Guinea	NL	Netherlands
BF	Burkina Faso	GR	Greece	NO	Norway
BG	Bulgaria	HU	Hungary	NZ	New Zealand
BJ	Benin	IE	Ireland	PL	Poland
BR	Brazil	IT	Italy	PT	Portugal
BY	Belarus	JP	Japan	RO	Romania
CA	Canada	KP	Democratic People's Republic of Korea	RU	Russian Federation
CF	Central African Republic	KR	Republic of Korea	SD	Sudan
CG	Congo	KZ	Kazakhstan	SE	Sweden
CH	Switzerland	LI	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovak Republic
CM	Cameroon	LU	Luxembourg	SN	Senegal
CN	China	LV	Latvia	TD	Chad
CS	Czechoslovakia	MC	Monaco	TG	Togo
CZ	Czech Republic	MG	Madagascar	UA	Ukraine
DE	Germany	ML	Mali	US	United States of America
DK	Denmark	MN	Mongolia	UZ	Uzbekistan
ES	Spain			VN	Viet Nam
FI	Finland				

-1-

Description

SINTERED SCREEN COMPLETION

Technical Field

This invention relates generally to well completion apparatus, and in particular to method and apparatus for suspending a sintered metal screen in a well bore.

5 Background of Art

In the course of completing an oil and/or gas well, it is common practice to run a string of casing into the well bore and then to run the production tubing inside the casing. At the well site, the casing is perforated
10 across one or more production zones to allow production fluids to enter the casing bore. During production of the formation fluid, formation sand is also swept into the flow path, and erodes production components.

In some completions, the well bore is uncased, and
15 an open face is established across the oil or gas bearing zone. Such open bore (uncased) arrangements are utilized, for example, in water wells, test wells and horizontal well completions. One or more sand screens are installed in the flow path between the production tubing and the perforated
20 casing (cased) or the open well bore face (uncased). A packer is customarily set above the sand screen to seal off the annulus in the zone where production fluids flow into the production tubing. The annulus around the screen may be packed with a relatively coarse sand or gravel which acts as
25 a filter to reduce the amount of fine formation sand reaching the screen.

-2-

Conventional sand screens employ a perforated mandrel which is surrounded by longitudinally extending spacer bars, rods or ribs and over which a continuous wire is wrapped in a carefully spaced helical configuration to provide a predetermined longitudinal gap between the wire turns. The aperture between turns permits formation fluids to flow through the screen, while the closely spaced wire turns exclude fine particulate materials such as sand or gravel which may penetrate the gravel pack.

10 Fine sand may be carried through the gravel pack before the gravel pack bridge stabilizes. During the early stages of producing the well after gravel packing, those fines tend to migrate through the gravel pack and screen and lodge within the inner annulus between the outer wire wrap and the perforated mandrel. In some instances, this can cause severe erosion of the screen and ultimate failure of the screen to reduce sand invasion.

One attempt to overcome the sand erosion problem is to interpose a prepack of gravel within the annulus between the inner mandrel and the outer wire screen. The prepacked gravel is sized appropriately to exclude the fines which accompany the formation fluid. Raw gravel, as well as epoxy resin coated gravel, have been used extensively in prepacked well screens. Some prepacked well screens are subject to retrieval problems due to their outer diameter being larger than that of a conventional well screen. In order to make prepacked well screens more easily retrievable, the inner mandrel is usually downsized, thereby imposing restrictions on both production and completion tool string bore sizing.

An improved sand screen which can exclude sand fines from inflowing formation fluid without limiting

-3-

production of the formation fluid has recently been introduced for use in oil and gas wells. The improved sand screen includes a tubular, porous body composed entirely of sintered, powdered metal. Such a sintered metal sand screen
5 is disclosed in U.S. Patent 5,088,554 assigned to Otis Engineering Corporation, and is hereby incorporated by reference.

Because helically wrapped wires and longitudinal spacer bars are not utilized, the radial thickness of the
10 sintered metal sand screen body provides the prepack gravel function with the desired porosity without imposing a reduction on the production bore size. The sintered metal sand screen has a unitary, tubular body of inherently stable, porous aggregate material, and has integrally
15 formed, threaded end fittings for attachment directly to production tubing. Because of its porosity and large surface area, the sintered metal sand screen is well adapted for use in completions having relatively low entrance velocity of formation fluids, for example, in horizontal
20 completions.

It is possible that after a conventional wire-wrap screen or a sintered metal screen has been installed in a well for a period of time, its structural integrity may be compromised by corrosion or sand erosion, in which case it
25 may be necessary to repair, replace or isolate the damaged screen. For that purpose, the present invention provides an improved method for installing a sintered metal screen in a well bore so that it can be retrieved for repair or replacement without retrieving the packer; the invention
30 provides method and apparatus for selectively isolating a damaged sand screen; and the invention provides method and apparatus for installing a sintered metal screen in combination with a damaged primary screen so that screened

-4-

production can continue without removal of the damaged primary screen.

Disclosure of the Invention

According to a first embodiment of the invention,
5 a sintered metal screen is releasably suspended from a packer mandrel by a locking mandrel and a landing nipple. In this arrangement, the landing nipple is attached to the lower end of the packer mandrel, and a sintered metal screen is attached to the lower end of the locking mandrel. The
10 locking mandrel is disposed in releasable, interlocking engagement with the landing nipple. The sintered metal screen and lock mandrel are retrievable with the assistance of a running tool which is insertable into the bore of the locking mandrel. Thus the sintered metal sand screen may be
15 removed and replaced without retrieving the packer or the production tubing.

In a second embodiment, the sintered metal screen is suspended from a locking mandrel which is received in interlocking engagement within the bore of the landing
20 nipple. The landing nipple is suspended from the lower end of the packer mandrel, and the sintered metal screen is enclosed within the bore of a sliding side valve. This arrangement is useful in multiple production zone completions, with the sliding side valve being opened and
25 closed as desired for selectively admitting production in various producing zones, or for isolation of a damaged screen.

In a third embodiment, a conventional wire-wrap sand screen is suspended from a landing nipple, with the
30 annulus being sealed above and below a producing zone by packers. In the event the conventional wire-wrap screen

-5-

should become damaged by erosion or corrosion, rather than replacing the screen, a sintered metal screen is run into the bore of the conventional wire-wrap screen. The sintered metal sand screen is suspended from the landing nipple by a
5 releasable lock mandrel. The sintered metal sand screen is thus interposed in the flow path for screening out sand fines which are conducted through the damaged conventional wire-wrap screen.

In yet another embodiment, a sintered metal sand
10 screen is fitted about the mandrel of a sliding side valve circulation tool. Flow from the well is conducted through the sintered metal screen and flows into the production tubing via the ports in the sliding side valve. The sliding side valve circulation tool may be opened and closed in both
15 single and multizone completions for production control purposes, or for isolation of a damaged screen.

According to another embodiment, a sintered metal sand screen is suspended from a hanger packer in a through-tubing completion.

20 Other features and advantages of the present invention will be appreciated by those skilled in the art upon reading the detailed description which follows with reference to the attached drawings.

Brief Description of the Drawings

25 FIGURE 1 is a simplified, schematic diagram showing a vertical section through a hydrocarbon formation which is intersected by a production well which has been completed with a sintered metal sand screen which is releasably suspended from a packer according to the
30 teachings of the present invention;

-6-

FIGURE 2 is a simplified, sectional view which illustrates the releasable attachment of a sintered metal sand screen to the lower end of a packer mandrel;

5 FIGURE 3 is a simplified, sectional view which illustrates the releasable installation of a sintered metal sand screen within the bore of a sliding side valve;

FIGURE 4 is a simplified, sectional view which illustrates the assembly of a sliding side valve as the internal mandrel for a sintered metal screen;

10 FIGURE 5 is a simplified, sectional view which illustrates the installation of an auxiliary sintered metal sand screen within the bore of a primary sand screen;

FIGURE 6 is a view similar to FIGURE 5 which illustrates the releasable installation of a sintered metal
15 sand screen within a conventional wire-wrap screen;

FIGURE 7 is a simplified, sectional view which illustrates a horizontal well completion in an uncased bore hole, in which a section of sintered metal screen is enclosed within the bore of a sliding side valve;

20 FIGURE 8 is a simplified, sectional view which illustrates a horizontal well completion in a cased bore hole, in which a section of sintered metal screen is enclosed within the bore of a sliding side valve; and,

FIGURE 9 is a simplified, sectional view which
25 illustrates installation of a sintered metal sand screen assembly where support is provided by a hanger packer in a through-tubing completion.

-7-

Best Mode for Carrying Out the Invention

In the description which follows, like parts are indicated throughout the specification and drawings with the same reference numerals, respectively. The drawings are not necessarily to scale and the proportions of certain parts have been exaggerated to better illustrate details of the invention.

Referring now to FIGURE 1, a hydrocarbon formation 10 is intersected by a production well 12. A tubular string of well casing 14 extends through multiple layers of overburden 16, traversing the hydrocarbon formation 10, and intersecting one or more layers of underburden 18. The tubular casing sections 14 which intersect the hydrocarbon formation 10 are perforated by multiple openings 20 formed through the casing sidewall to permit inflow of formation fluids from the adjoining hydrocarbon bearing formation 10.

The hydrocarbon formation 10 is confined vertically between the overburden layer 16 and the underburden layer 18, typically of an impervious siltstone or other barren rock. The sand screen assembly of the present invention is particularly well adapted to a generally horizontally aligned hydrocarbon formation, such as the formation 10 as illustrated, having a thickness ranging from about 100 feet (30.48 meters) to about 500 feet (152.4 meters). For illustrative purposes, the hydrocarbon formation 10 is described at a depth of 7,500 feet (2286 meters), with a reservoir pressure of 2,000 psi (1.4×10^6 Kgs/sq. meter) and a reservoir temperature of 130 degrees F (54.4 degrees C). The overburden layer 16 and the subjacent underburden layer 18 are impervious to the flow of gas.

Referring now to FIGURE 1 and FIGURE 2, the

-8-

production well 12 is completed by multiple screens S1, S2, S3, S4 which are supported by a lower tubing string 22. The lower tubing string 22 is suspended from landing nipple 24 attached to the mandrel 26 of a production packer 28. The
5 production packer 28 includes anchor slips 30 and an elastomeric seal 32 which releasably secure and seal the packer against the bore of the tubular well casing 14. Formation fluid produced through the screens S1-S4 and the production tubing 22 flows to the surface through an upper
10 tubing string 34 to a wellhead assembly 36. The wellhead assembly 36 supports the upper end of the production tubing string 34 and seals the casing 14. Formation fluid 38 is conveyed to a surface reservoir through a production flow line 40.

15 The sand screens S1, S2, S3 and S4 have substantially identical construction, each having a tubular screen body 42 which is a unitary, porous body of sintered powdered metal. The metal preferably is a corrosion resistant metal such as stainless steel or nickel and nickel
20 chromium alloys such as are sold under the trademarks MONEL and INCONEL. In this embodiment, the sintered metal screen body provides a matrix having a pore size of about 100 - 150 microns, corresponding to 40 - 60 mesh. The screen S1 has tubular end portions 44, 46 which are fitted with threaded
25 connections for attachment to the production tubing 22 on the upper end, and for attachment to a bull plug 48 on the lower end. The bull plug seals the lower end of the sand screen bore, thus constraining the formation fluid 38 to flow through the porous sidewall 42 and upwardly through the
30 production bores of the tubing 22 and tubing 34.

It will be appreciated that the sand screens S1, S2, S3 and S4 are subject to damage by corrosive fluids as well as sand fines which are swept into the flow path.

-9-

Consequently, it may be necessary to repair or replace the sand screens from time to time. According to an important feature of the present invention, the sand screens are releasably suspended from the packer 28 by a locking mandrel 50 which is disposed in releasable, interlocking engagement with the landing nipple 24. In this arrangement, the landing nipple 24 is attached to the lower end of the packer mandrel 26. The landing nipple 24 has a tubular mandrel 52 which is intersected by a longitudinal bore 54 which is connected in flow communication with the packer mandrel bore 28B. The landing nipple mandrel 52 is radially intersected by an internal annular slot 56 for receiving a radially deflectable locking key 58 carried by the locking mandrel 50. As can be seen in FIGURE 2, the locking mandrel 50 is received in releasable, interlocking engagement with the landing nipple 24. The lower tubing string 22 is attached to the locking mandrel 50, thus suspending the sand screens S1, S2, S3 and S4 at the appropriate depth corresponding with the production zone 10.

The sintered metal screens S1-S4, the lower tubing string 22 and the locking mandrel are retrievable with the assistance of a running tool which is insertable into the bore of the locking mandrel 50. When the running tool engages the locking mandrel, locating dogs on the running tool engage and locate the lower end of a nipple hone bore. Further upward movement through the nipple results in the running tool causing an expander sleeve to move down, which offsets the bend in the bias springs. This causes the bias springs and the locking keys to move to the locating position. The locking keys flex from the locating position to the retracted position when being pulled across the nipple locator dogs. Thus, installation and retrieval of the sand screens can be carried out, without removing the packer.

-10-

Referring now to FIGURE 3, a sintered metal sand screen 60 is suspended from the locking mandrel 50. The landing nipple 24 is secured to the packer mandrel 26 and the sintered metal screen 60 is suspended from the lower end of the locking mandrel 50, as previously discussed. In addition, the sintered metal screen 60 is enclosed within the bore of a sliding side valve 62. The sliding side valve 62 is a circulation tool having a tubular mandrel 64 intersected by a longitudinal production bore 66 and having a sidewall portion radially intersected by a circulation port 68. A tubular sleeve 70 is slidably received within the bore of the circulation sub for opening and closing the circulation port 68. The circulation sub mandrel 64 is connected at its upper end to the landing nipple 24, and at its lower end to a second production packer 71.

According to this arrangement, the first production packer 28 and the second production packer 71 isolate the annulus within a production zone. Formation fluid entering through the well casing perforations 20 flows through the flow port 68 of the circulation sub 62. Because the lower end of the sintered metal sand screen 60 is sealed by the bull plug 48, the formation fluid is constrained to flow through the sintered metal sidewall of the sand screen 60, and upwardly through the bore of the first production packer 24. The sintered metal sand screen 60 can be retrieved as previously discussed, and the sliding side door sleeve valve can be moved to the closed position, thereby blocking the flow port 68 and isolating the production zone, without removing the production packers 28, 71.

Referring now to FIGURE 4, a sintered metal sand screen 72 is fitted about the circulation sub 62. The sintered metal sand screen 72 has tubular end portions 74, 76 which are fitted with threaded connections for attachment

-11-

to connecting subs 78, 80, respectively. The connecting subs 78, 80 connect the circulation sub 62 to the mandrel of the packer 28, and to the mandrel of the lower packer 71. The end collars 74, 76 are attached to the connecting subs
5 by threaded fittings, or alternatively, by welds.

Referring now to FIGURE 5, the sintered metal sand screen 72 is suspended from the landing nipple 24 by the connecting sub 80. In this embodiment, the sintered metal sand screen 72 serves as a primary sand screen, and its
10 operation is enhanced by an auxiliary sand screen 82. In this arrangement, the well annulus in the production zone is isolated by the upper and lower production packers 28, 71 as previously discussed. Formation fluid enters through the well casing perforations 20 and is conducted through the
15 permeable sidewall of the primary sintered metal screen 72. If the primary screen 72 should become damaged by sand erosion or corrosion, rather than replacing the screen 72, the auxiliary sintered metal screen is run into the bore of the primary screen as shown in FIGURE 5. According to this
20 arrangement, the auxiliary sintered metal sand screen 82 is interposed in the flow path for screening out sand fines which are conducted through the damaged primary sand screen.

The lower end of the auxiliary sintered metal sand screen 82 is sealed by a bull plug 48. The auxiliary sand
25 screen 82 is provided with end collars 84, 86. The upper collar 86 is fitted with threads for attachment to a coupling sub 88. The lower coupling collar 84 has a polished external surface. The lower polished collar 84 is coupled in sealing engagement with a coupling collar 90
30 connected to the lower end of the auxiliary sand screen 82. The coupling collar 90 has a polished bore for receiving the polished external surface of the collar 84. The interface between the sealing collar 84 and the coupling collar 90 is

-12-

sealed by an annular O-ring seal 92. According to this arrangement, formation fluid from below the lower production packer 71 is blocked, and only formation fluid entering through the well casing perforations 20 in the production zone enter through the primary sintered metal sand screen 72.

Referring now to FIGURE 6, a similar installation is disclosed in which the primary sand screen is a conventional wire-wrap screen 94. The primary sand screen

-13-

Referring now to FIGURE 9, a sintered metal sand screen 104 is suspended from a hanger packer 106 in a through-tubing completion. Such completions may be used, for example, in offshore installations, in which it is desirable that the tubing weight be transferred to the casing 14 below the mud line. It is also intended for installations where it is desirable to retrieve and reinstall tubing removable safety valves without disturbing the production tubing or the downhole production packer.

10 In the through-tubing embodiment of FIGURE 9, the upper production tubing string 34 is stabbed and sealed against the mandrel bore of a production packer 108. The production packer 108 is equipped with anchor slips 110 which are movably mounted on a tubular body mandrel 112 for radial expansion into set engagement against the well casing 14. The production packer 108 is also equipped with annular seal elements 114 which are expandable into sealing engagement against the well casing 14.

The sintered metal sand screen 104 is coupled to the hanger packer 106 by a tubular extension sub 116 and an overshot tubing seal divider 118. The sand screen 104 and the extension sub 116 are centered within the bore of the well casing 14 by bow spring centralizers 120, 122. The hanger packer 106, tubular extension sub 116, and the sintered metal sand screen 114 may be suspended within the upper production tubing 34 by various means, including a braided line, reeled tubing or, as shown in this exemplary embodiment, a jointed string of auxiliary production tubing 124. The auxiliary production tubing string 124 is concentrically disposed within the upper production tubing string 34, and is releasably attached to the wellhead 36 at the surface.

-14-

The through-tubing installation shown in FIGURE 9 permits most of the tubing weight of the sand screen assembly, extension sub, and hanger packer to be transferred to the casing below the mud line, or at some other
5 predetermined point downhole where the well casing has good lateral support. The hanger packer 106 is designed for release from the well casing with a straight upward pull, so that the sintered metal sand screen 104 may be retrieved to the surface for replacement, without disturbing the
10 production packer 108 or the primary production tubing 34.

Although the invention has been described and illustrated with respect to a preferred embodiment, it should be understood that the present disclosure has been made by way of example only and that changes in the
15 arrangement and combination of parts may be made by those skilled in the art without departing from the spirit and scope of the invention as claimed.

-15-

Claims

1. Well completion apparatus comprising, in combination:

a packer including a body mandrel having a longitudinal bore defining a production flow passage, anchor slips movably mounted on said packer body mandrel for radial expansion into set engagement against a well casing, and an annular seal element mounted on said body mandrel for radial expansion into set engagement against a well casing, thereby providing an annular fluid seal across the annulus between the body mandrel and a well casing in the radially expanded, set condition;

a landing nipple attached to said packer body mandrel, said landing nipple having tubular mandrel intersected by a longitudinal bore disposed in flow communication with said packer mandrel bore;

a locking mandrel disposed in releasable interlocking engagement with said landing nipple, said locking mandrel being intersected by a longitudinal bore defining a flow passage in flow communication with said packer mandrel bore; and,

a sand screen coupled to said locking mandrel, said sand screen having a tubular, porous body composed of sintered powdered metal, and a longitudinal flow passage disposed in flow communication with said packer mandrel bore.

2. Well completion apparatus as defined in claim 1, said tubular sand screen including a plug attached to the lower end of said tubular, porous body for sealing the

-16-

longitudinal flow passage of said sand screen.

3. Well completion apparatus as defined in claim 1, including:

a circulation sub having a tubular mandrel
5 intersected by a radial circulation port and by a longitudinal bore defining a flow passage, and having a tubular sleeve mounted within the bore of said circulation mandrel for opening and closing the circulation port, the mandrel of said circulation sub being suspended from said
10 landing nipple, and said sand screen being concentrically disposed within the bore of said circulation sub.

4. Well completion apparatus comprising, in combination:

a first packer including a body mandrel
15 having a longitudinal bore defining a production flow passage, anchor slips movably mounted on said packer body mandrel for radial expansion into set engagement against a well casing, and an annular seal element mounted on said body mandrel for radial expansion into set engagement
20 against a well casing, thereby providing an annular fluid seal across the annulus between the body mandrel and a well casing in the radially expanded, set condition;

a second packer including a body mandrel
having a longitudinal bore defining a production flow
25 passage, anchor slips movably mounted on said packer body mandrel for radial expansion into set engagement against a well casing, and an annular seal element mounted on said body mandrel for radial expansion into set engagement against a well casing, thereby providing an annular fluid
30 seal across the annulus between the body mandrel and a well

-17-

casing in the radially expanded, set condition;

a circulation sub having a tubular mandrel intersected by a longitudinal production bore and having a sidewall portion radially intersected by a circulation port, and having a tubular sleeve slidably received within the bore of said circulation sub for opening and closing the circulation port, the mandrel of said circulation sub being coupled to the mandrels of said first and second packers, thereby defining a longitudinal flow passage therebetween; and,

a tubular sand screen mounted on said circulation sub, said sand screen having a tubular, porous sidewall composed of sintered powdered metal disposed in radially spaced relation with respect to said circulation sub.

5. Well completion apparatus comprising, in combination:

a first packer including a body mandrel having a longitudinal bore defining a production flow passage, anchor slips movably mounted on said packer body mandrel for radial expansion into set engagement against a well casing, and an annular seal element mounted on said body mandrel for radial expansion into set engagement against a well casing, thereby providing an annular fluid seal across the annulus between the body mandrel and a well casing in the radially expanded, set condition;

a second packer including a body mandrel having a longitudinal bore defining a production flow passage, anchor slips movably mounted on said packer body mandrel for radial expansion into set engagement against a

-18-

well casing, and an annular seal element mounted on said body mandrel for radial expansion into set engagement against a well casing, thereby providing an annular fluid seal across the annulus between the body mandrel and a well casing in the radially expanded, set condition;

a landing nipple coupled to the mandrel of said first packer, said landing nipple having a tubular mandrel intersected by a longitudinal bore disposed in flow communication with the mandrel bore of said first packer;

10 a locking mandrel disposed in releasable, interlocking engagement with said landing nipple, said locking mandrel being intersected by a longitudinal bore defining a flow passage disposed in flow communication with said packer mandrel bore;

15 a primary sand screen having a first tubular end portion coupled to the mandrel of said landing nipple and having a second tubular end portion coupled to the mandrel of said second packer, and having a fluid porous, particulate-restricting member extending between said first and second tubular end portions, said fluid porous, particulate-restricting member having a tubular bore defining a fluid flow passage;

25 an auxiliary sand screen received within the production bore of said primary sand screen, said auxiliary sand screen having a tubular, porous body composed of sintered powdered metal, and having a longitudinal flow passage disposed in flow communication with the mandrel bore of said first packer; and,

30 sealing means coupled to said primary sand screen and to said auxiliary sand screen for sealing the

-19-

annulus between said primary and secondary sand screens, and for sealing the longitudinal flow passage on the lower end of said auxiliary sand screen.

6. Well completion apparatus as defined in claim 5, wherein said primary sand screen comprises a tubular, porous body composed of sintered powdered metal.

7. Well completion apparatus as defined in claim 5, wherein said primary sand screen comprise a perforated mandrel and an wire screen mounted on said mandrel, said wire screen having a screen wire wrapped externally about said perforated mandrel, thereby defining longitudinally spaced outer screen apertures for conducting formation fluid through said primary screen.

8. Well completion apparatus as defined in claim 5, including a coupling collar disposed intermediate said primary sand screen and the mandrel of said second packer, said coupling collar having a polished bore, and further including annular seal means disposed between the polished bore and the auxiliary screen mandrel.

9. Well completion apparatus as defined in claim 5, said auxiliary sand screen including a plug attached to the lower end of said tubular, porous body for sealing the longitudinal flow passage of said auxiliary sand screen.

10. An improved sand screen assembly for separating particulate material from formation fluid comprising, in combination:

a first packer including a body mandrel having a longitudinal bore defining a production flow passage, anchor slips movably mounted on said packer body

-20-

mandrel for radial expansion into set engagement against a well casing, and an annular seal element mounted on said body mandrel for radial expansion into set engagement against a well casing, thereby providing an annular fluid seal across the annulus between the body mandrel and a well casing in the radially expanded, set condition;

a second packer including a body mandrel having a longitudinal bore defining a production flow passage, anchor slips movably mounted on said packer body mandrel for radial expansion into set engagement against a well casing, and an annular seal element mounted on said body mandrel for radial expansion into set engagement against a well casing, thereby providing an annular fluid seal across the annulus between the body mandrel and a well casing in the radially expanded, set condition;

a primary sand screen having a first tubular end portion coupled to the mandrel of the first packer and having a second tubular end portion coupled to the mandrel of the second packer, said primary sand screen having a fluid porous, particulate-restricting member extending between said first and second tubular end portions, said fluid porous, particulate-restricting member having a tubular bore defining a fluid flow passage;

an auxiliary sand screen received within the production bore of said primary sand screen, said auxiliary sand screen having a tubular, porous body composed of sintered powdered metal, and having a longitudinal flow passage disposed in flow communication with the mandrel bore of said first packer; and,

sealing means coupled to said primary sand screen and to said auxiliary sand screen for sealing the

-21-

annulus between said primary and secondary sand screens, and for sealing the longitudinal flow passage on the lower end of said auxiliary sand screen.

11. An improved sand screen assembly as defined
5 in claim 10, wherein said primary sand screen comprises a tubular, porous body composed of sintered powdered metal.

12. An improved sand screen assembly as defined
in claim 10, wherein said primary sand screen comprises a
10 perforated mandrel and a wire screen mounted on said mandrel, said wire screen having a screen wire wrapped externally about said perforated mandrel, thereby defining longitudinally spaced, outer screen apertures for conducting formation fluid through said primary screen.

13. An improved sand screen assembly as defined
15 in claim 10, including a coupling collar disposed intermediate the primary sand screen and the mandrel of said second packer, said coupling collar having a polished bore, and further including annular seal means disposed between the polished bore and the auxiliary screen mandrel.

20 14. An improved sand screen assembly as defined in claim 10, said auxiliary sand screen including a plug attached to the lower end of said tubular, porous body for sealing the longitudinal flow passage of said auxiliary sand screen.

25 15. Apparatus for completing a well of the type having a well casing extending between a subterranean production zone and a surface wellhead assembly comprising, in combination:

a first packer including a body mandrel

-22-

having a longitudinal bore defining a production flow passage, anchor slips movably mounted on said packer body mandrel for radial expansion into set engagement against the well casing, and an annular seal element mounted on said
5 body mandrel for radial expansion into set engagement against the well casing, thereby providing an annular fluid seal across the annulus between the body mandrel and the well casing in the radially expanded, set condition;

10 a first production tubing string having a first end portion coupled to the body mandrel of said first packer and having a second end portion adapted for attachment to the wellhead assembly;

15 a second packer disposed with the bore of the first production tubing string, said second packer including a body mandrel having a longitudinal bore defining a production flow passage, anchor slips movably mounted on the body mandrel of said second packer for radial expansion into set engagement against the sidewall of the first production tubing string, and an annular seal element mounted on said
20 body mandrel for radial expansion into set engagement against the sidewall of the first production tubing string, thereby providing an annular fluid seal across the annulus between the body mandrel and said first production tubing string in the radially expanded, set condition;

25 a second production tubing string having a first end portion coupled to the body mandrel of said second packer and having a second end portion adapted for attachment to the wellhead assembly;

30 a third production tubing string having a first end portion projecting through the body mandrel bore of said first packer and coupled to the body mandrel of the

-23-

second packer, and having a second end portion suspended within the well casing intermediate the first packer and the production zone; and,

5 a sand screen coupled to the second end portion of the third production tubing string, said sand screen having a tubular, porous body composed of sintered powdered metal, and having a longitudinal flow passage disposed in flow communication with the body mandrel bore of the second packer.

1 / 5

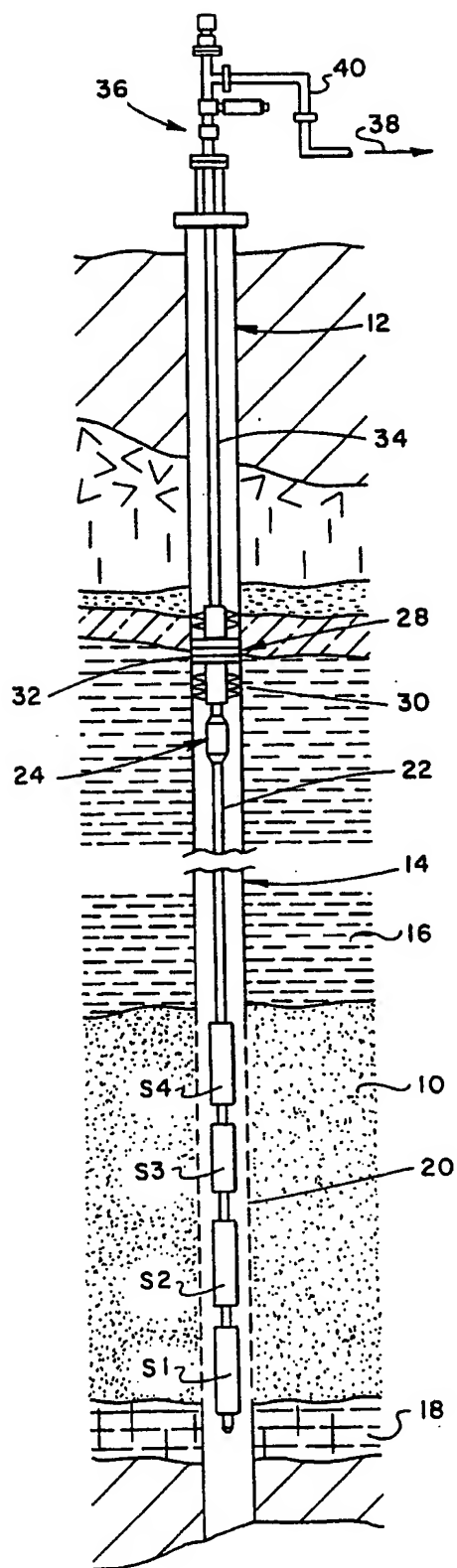


FIG. 1

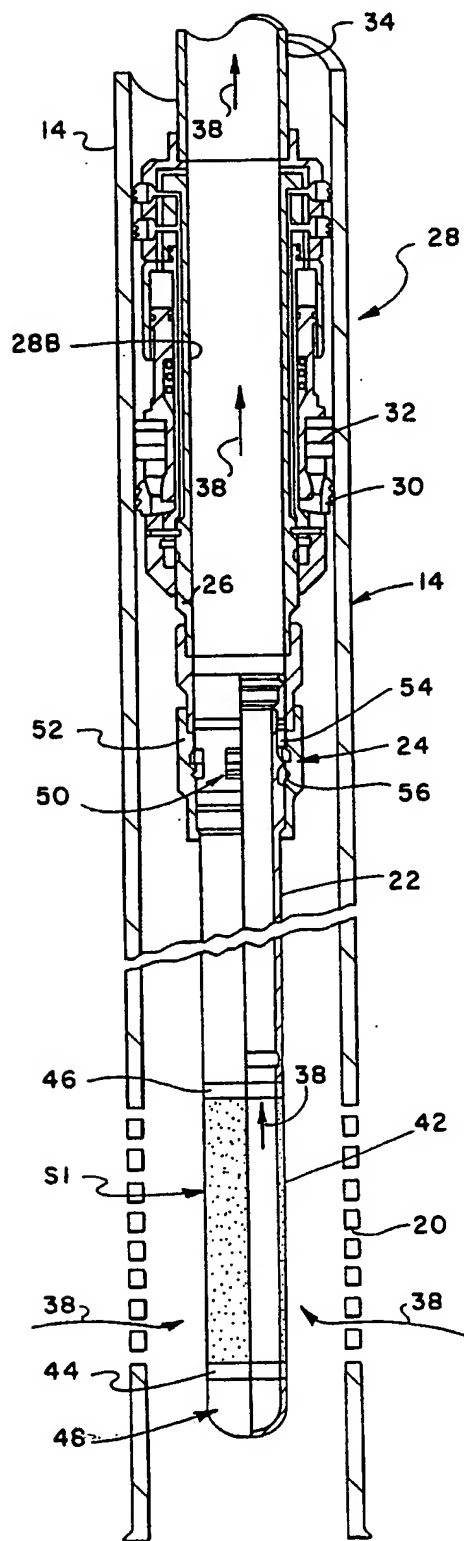


FIG. 2

SUBSTITUTE SHEET

2 / 5

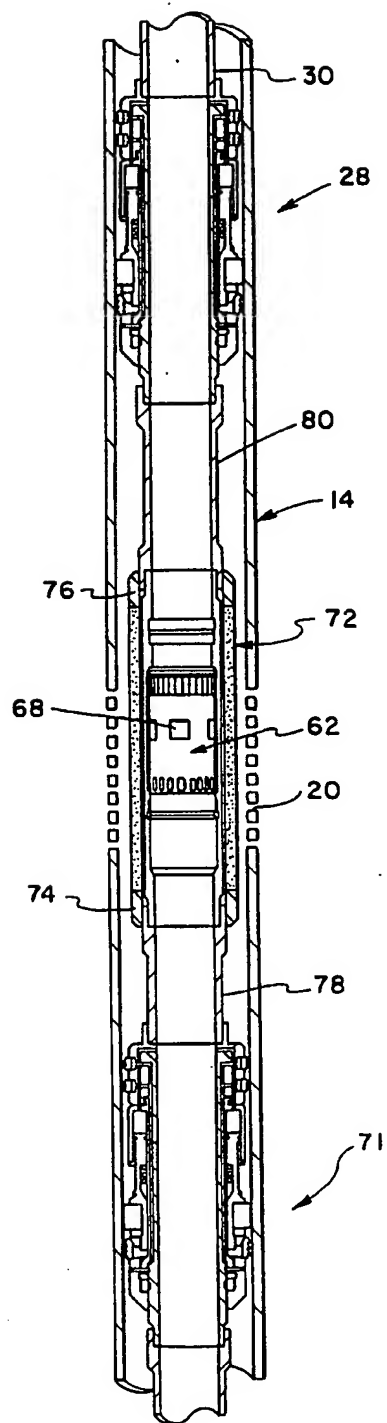
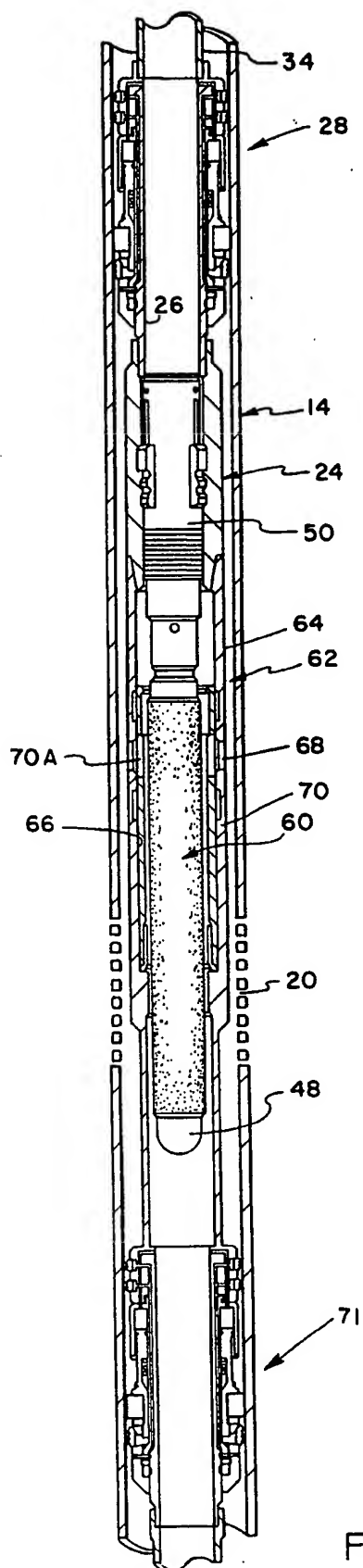


FIG. 3

FIG. 4
SUBSTITUTE SHEET

3 / 5

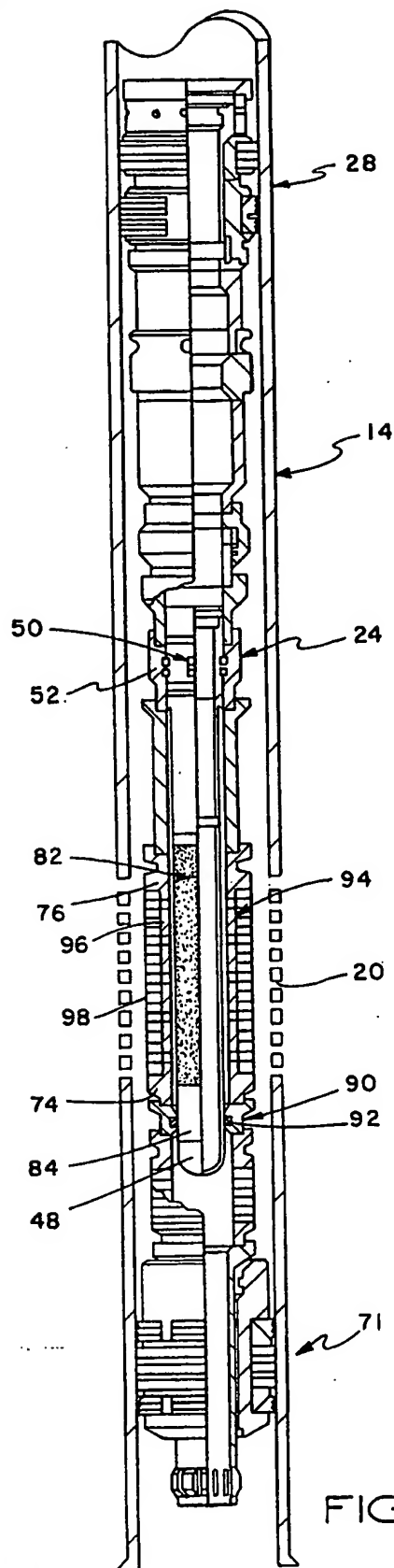
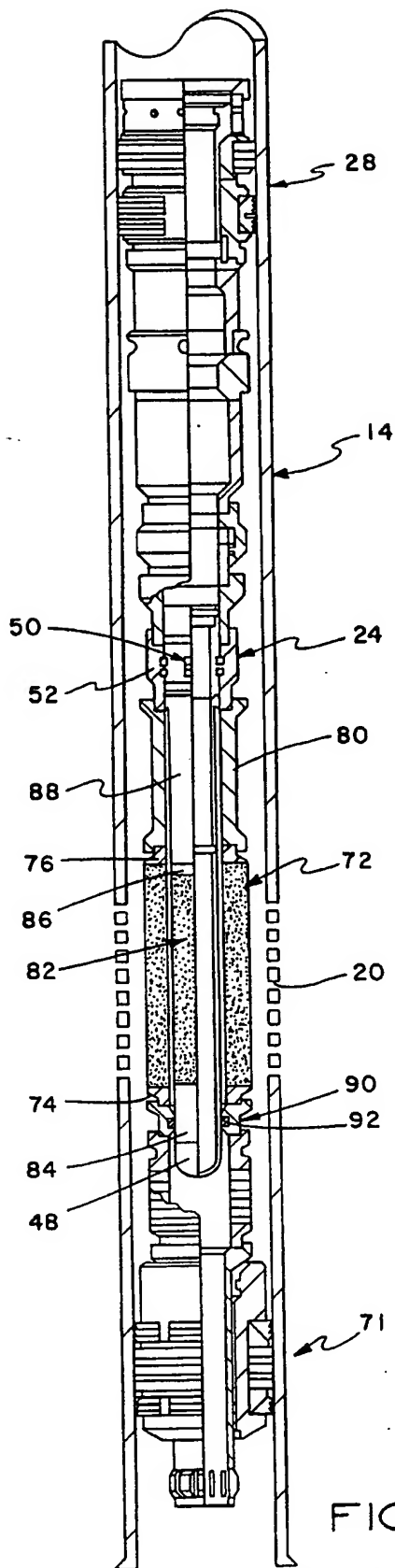


FIG. 5

FIG. 6

SUBSTITUTE SHEET

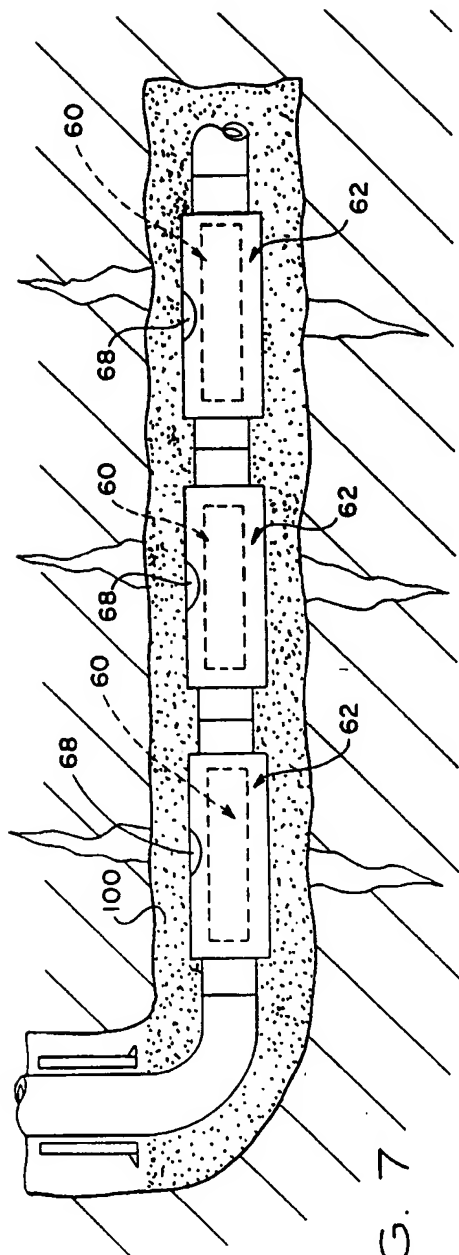


FIG. 7

SUBSTITUTE SHEET

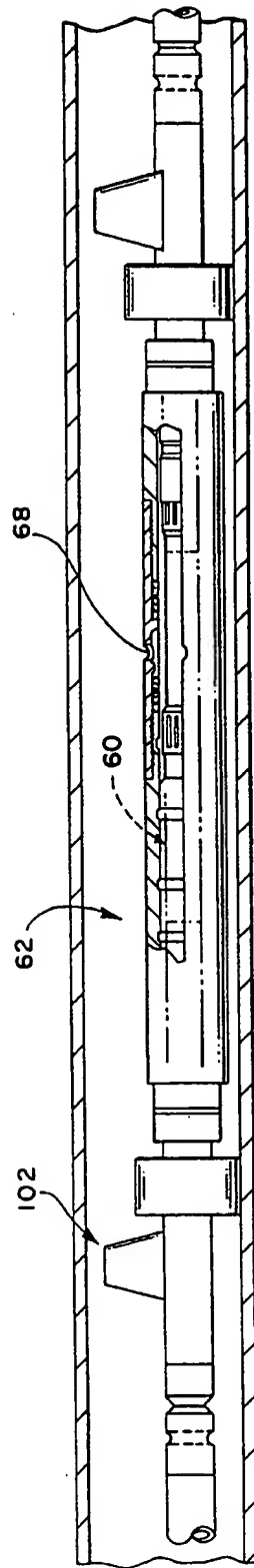


FIG. 8

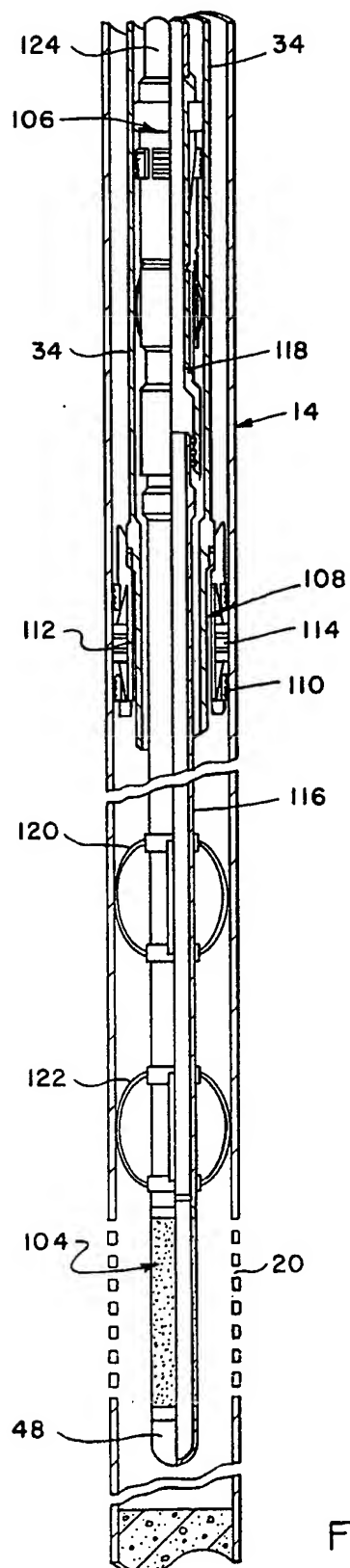


FIG. 9

SUBSTITUTE SHEET

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/07146

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :E21B 43/08, 43/12, 23/02, 33/12

US CL :166/228, 115, 147

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,860,831 (Caillier) 29 August 1989. See Figure 7.	1, 2
Y	US, A, 4,856,590 (Caillier) 15 August 1989. See Figure 5.	1, 2
Y	US, A, 2,902,096 (Stewart) 01 September 1959. See slips 12, 13 and column 2 lines 55-60.	1, 2
Y	US, A, 5,088,554 (Arterbury et al.) 18 February 1992. See column 2 line 64 through column 3 line 43.	1, 2

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be part of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reasons (as specified)	"A" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

09 SEPTEMBER 1993

Date of mailing of the international search report

13 OCT 1993

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Authorized officer

HOANG DANG

Facsimile No. NOT APPLICABLE

Telephone No. (703) 308-2168

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/07146

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,825,944 (Mays) 02 May 1989. See check valves 33 and 34 and column 5 lines 38-40.	2
A	US, A, 4,254,832 (Patton et al.) 10 March 1981. See Figures 1-5	1-15
A	US, A, 3,437,135 (Cox et al.) 08 April 1969. See Figure 1.	1-15

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/07146

B. FIELDS SEARCHED

Minimum documentation searched

Classification System: U.S.

166/74, 157, 158, 205, 51, 227, 229, 236, 116